VOLUME 76 SEPARATE No. 40

ROCHESTER 4, N.Y.

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

OCTOBER, 1950

CONSTRUCTION TECHNIQUE OF PASSING FLOODS OVER EARTH DAMS

By Andrew Weiss, Hon. M. ASCE

IRRIGATION DIVISION

Copyright 1950 by the AMERICAN SOCIETY OF CIVIL ENGINEERS
Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N.Y.

PRICE $0.50 PER COPY

TD 620.6

The Society is not responsible for any statement made or opinion expressed in its publications

---

Published at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York 18, N. Y. Reprints from this publication may be made on condition that the full title of paper, name of author, page reference, and date of publication by the Society are given.

Proceedings—Vol. 76 October, 1950 Separate No. 40

AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

PAPERS

CONSTRUCTION TECHNIQUE OF PASSING FLOODS OVER EARTH DAMS

By Andrew Weiss,[1] Hon. M. ASCE

Synopsis

The increasing necessity of using earth dams because of the diminishing number of sites suitable for the construction of masonry or concrete dams has created new problems in dam construction, more especially in locations where climatic, geologic, and topographic conditions tend to produce floods which, during construction, are difficult to control by conventional devices, such as tunnels or covered by-passes. The problem is further complicated where scarcities of equipment, repair parts, and trained personnel accentuate the problem. These conditions occur in Mexico, particularly the extraordinary floods, the relative scarcity of equipment, the limited financial resources, and the relative unpreparedness of the construction agency charged with the undertaking. This paper concerns problems of this character, and the solutions adopted.

Irrigation in Mexico

Irrigation is a national necessity in Mexico, a condition quite distinct from irrigation in the United States where the 100th meridian is generally considered to be the limiting line for irrigation practice, and where a 30-in. annual rainfall is ample for successful farming. In Mexico an annual rainfall as great as 6 ft, erratically distributed in a subtropical climate, makes irrigation wholly desirable and even necessary for completely successful agriculture. This has been the experience in such states as Veracruz, Tamaulipas, and Chiapas, as well as in other localities.

Another condition that is quite prevalent in Mexico is the general absence of good reservoir sites in the mountainous regions. Acceptable sites are generally in the lower foothills; but in Mexico such ideal dam sites are most often difficult to find. Generally, the topography of Mexico is characterized

Note.—Written comments are invited for publication; the last discussion should be submitted by April 1, 1951.

[1] Cons. Engr., National Comm. of Irrig., Mexico, D. F., Mexico.

by an abrupt transition from the mountain region to the valley lands below, the latter being exposed to violent floods and innundations. Such conditions require multiple-purpose reservoirs which serve irrigation, flood control, and (as soon as the growth of the region justifies the investment) power development. Storage for irrigation is a national need because even the largest rivers have but little water in the rainless period. Ice and snow deposits occur only in a few isolated spots, such as the peaks of Ixtaccihuatl, in the State of Mexico, and Orizaba and Popocatepetl, in the State of Veracruz, which are very limited in extent. In other words, the mountains of Mexico are too far south to serve as collectors of any considerable part of the moisture that might be stored in the form of snow or ice deposits. All the foregoing conditions point to the necessity of artificial storage to provide for complete and successful use of the available water supply.

TABLE 1.—Comparison of Design Characteristics of Four Earth-Fill and Rock-Fill Dams in Mexico

Dam	Elevations, in Feet Above Sea Level			Catchment area, in square miles	Average annual runoff, in acre-feet	Spillway capacity, in cubic feet per second
	River	Crown	Spillway crest			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
San Ildefonso	7,150	7,353	7,336.6	149.4	76,960	21,180
Azúcar	148.0	287	250.0	11,418.0	987,000	800,000
Palmito	5,068.0	5,346.4	5,314.0	7,000.0	1,068,000	211,800
Valsequillo	6,500.0	6,770.0	6,753.5	1,560.0	316,000	39,000

It was in the creation of storage reservoirs on this considerable scale that the dam construction technique described in this paper was developed. Examples selected for illustration (see Table 1) are: San Ildefonso Dam in the State of Querétaro; Azúcar Dam at Camargo, Tamaulipas; Palmito Dam 100 miles upstream from Torreón, in the State of Durango; and Valsequillo Dam near Puebla, in the State of Puebla.

San Ildefonso Dam

A rock-fill dam on the Prieto River about 15 miles upstream from the town of San Juan del Río in the State of Querétaro is called "San Ildefonso." It is situated in a narrow canyon that crosses a series of basalt flows intercalated with layers of basaltic agglomerates. This is one of the conventional types of rock-fill dams, provided with a concrete "blanket" on the water side. The maximum height above the river bed is 203 ft, the width of the crown is 16.4 ft, and the side slopes are 1 on 1.4. The upstream concrete face is reinforced with $\frac{3}{4}$-in.-round deformed bars, spaced 1 ft, center to center, in both directions and its thickness varies from 20.5 in. at the base to 8 in. at the crown, a variation of 1.08 in. for every 33 ft upward along its slope (approximately). This concrete blanket rests on a hand-placed rock fill which, in turn, rests on the dumped rock; and the slope of the latter is limited to 1 on 1.27 upstream and 1 on 1.4 downstream. The limiting range of slopes for the hand-placed rock

fill is between 1 on 1.27 and 1 on 1.4, with a maximum thickness of 25.6 ft at the foundation and 3 ft at the crown. The spillway is a fixed overflow crest, 16.4 ft below the crown of the dam, designed to discharge 21,180 cu ft per sec when the water depth on the crest is 10 ft. A horseshoe diversion tunnel 12.5 ft in diameter is used for control purposes.

The contractor, provided with only moderate means, soon found himself with insufficient time to complete the dam to a height that would pass the anticipated flood flows. In the circumstances, it was agreed that the contractor should be permitted to continue the rock fill provided that he protected the downstream slope with an exposed mesh of $\frac{3}{4}$-in. round reinforcing bars. As shown in Fig. 1, the center-to-center spacing was, for horizontal bars, 1 ft on centers and for sloping bars, 4 ft on centers, wired together at the intersections. This steel mesh was thus anchored to the rock fill by 13-ft steel bars, with hooks at both ends, spaced 3 ft vertically and 4 ft horizontally.

FIG. 1.—EMBANKMENT PROTECTION DURING THE CONSTRUCTION OF SAN ILDEFONSO DAM IN QUERÉTARO

Results.—The rock fill had reached a height of 36 ft on August 2, 1939, when the first flood began to pass over it. From the high water marks on the canyon walls the discharge was estimated at 4,070 cu ft per sec. No additional height was given to this rock fill following this flood because the contractor decided to employ his forces on other work during August and September.

On September 11 a second flood, of greater magnitude, passed over the rock fill, leaving marks on the canyon walls that indicated an overflow depth of 6.56 ft near the downstream crest. Applying the usual formula for broad-crested weirs, this would indicate a total discharge of 8,000 cu ft per sec, of which (possibly) 3,000 cu ft per sec passed through the diversion tunnel. Figs. 1 and 2 showing conditions as of September 22, 1939, demonstrate that neither of these floods left the smallest indication of erosion. The only defect notice-

able was a slight bulging along the foot of the downstream slope, where the mesh was slightly displaced because of insufficient anchorage; but no loss was noticeable in the rock fill.

After this second flood the contractor estimated that the flood period was safely past and removed the mesh. This was premature, as demonstrated on October 3, 1939, when a third flood tore away 7,000 cu m (9,000 cu yd) of rock fill; but the reduced height tended to regulate by storage rather than increase the depth of water over the temporary crest. When construction began after this third flood period the protection was considered no longer necessary. As the height of the dam increased, it was estimated that any known or recorded floods, that might be repeated in that season, could thereafter be controlled by the tunnel and the regulating capacity of the reservoir. All the bars were later recovered and used as originally intended, except the anchor bars which remained embedded in the rock fill.

Fig. 2.—Downstream Slope of San Ildefonso Dam in Querétaro, September 22, 1939

Summary.—Weaknesses in the technique, revealed by this experience, suggested the possibility that the anchorage at the bottom of the slope was relatively inadequate, that conditions for cleaning the river bed of loose rock could have been improved, and that the spacing of vertical bars could well have been reduced from 4 ft to 3 ft, center to center. At the bottom of the slope, where insufficient stripping made anchorage difficult, a concrete cover or footing would have protected this part of the mesh from the effects of severe dynamic impact that always threaten to undercut and destroy the protecting device.

Marte Goméz (El Azúcar) Dam

Azúcar Dam is an earth structure about 8 miles upstream from the mouth of the San Juan River, where it joins the Río Grande. The Town of Rio Grande

is on the American side and the Town of Camargo, on the Mexican side. The population in the valley below this dam is so dense that no flood risks were even remotely permissible greater than those ordinarily imposed by nature. The embankment slopes were as follows (vertical on horizontal):

Description	Slope
Impervious center, upstream side	1 on 3
Impervious center, downstream side	1 on 0.5
Semi-impervious fill, downstream side	1 on 2
Pervious gravel fill, both sides (to El. 240)	1 on 6

Materials Used in Embankment.—The impervious core is composed of a sandy loam containing from 20% to 30% clay taken from the river terrace along the left side (facing downstream). The central zone is supported on both sides by a gravelly earth fill, taken from the locally known Reynosa formation. On the left side of the stream bed, facing downstream, about a half mile of this dam rests on an alluvial river terrace about 50 ft deep. For this reason it was given an ample base width by the adoption of a 1 on 6 slope on both faces up to an elevation of 42.5 ft below the crown. On the upstream slope, wave protection is provided by a layer of loose rock, 3.28 ft thick. The Reynosa gravels provide the necessary filter between the rock fill and the center core.

This dam presented a special flood control problem. The records of the International Boundary Commission (IBC) revealed one flood of 350,000 cu ft per sec within quite recent times. Little thought was given to flood diversion by tunnels or covered conduits because of the size of the floods to be expected and the fact that there is no well defined dry season. Almost the only two months free from floods were February and March. The floods that occurred during the building of this dam are recorded in Table 2. The flood of 233,000 cu ft per sec that occurred on August 30, 1938, filled the channel to an elevation of about 65 ft above the river bed and inundated the borrow area on the left side of the stream. When the superintendent undertook to clean the river channel before beginning to excavate, he found it necessary to remove from 15 ft to 20 ft of river debris in order to reach the impervious mudstone suitable for the foundation of the impervious section. A large volume of talus material was also discovered along the right side. These deposits had served as a necessary support to hold the mudstone composing the right river bank from sliding;

TABLE 2.—RECORD OF FLOOD DISCHARGES (CUBIC FEET PER SECOND) DURING THE CONSTRUCTION OF AZÚCAR DAM IN TAMAULIPAS

Month and day	1938	1939	1940	1941
January 27	....	....	....	16,000
March 25	....	....	11,700	....
April 27	....	....	....	16,000
April 30	....	4,520	....	....
May 14	....	23,800	....	....
May 24	6,350	....	....	....
May 25	....	....	38,500	....
June 25	....	....	....	50,000
July 13	....	....	....	12,300
July 25	5,500	....	....	....
August 20	233,000	....	16,200	....
Sept. 1	29,500	....	....	....
Sept. 9	....	....	39,900	....
Sept. 10	....	....	....	72,700
Sept. 30	....	9,850	....	....
Oct. 11	....	65,000	....	....
Oct. 30	....	....	22,600	....
Dec. 22	....	....	21,400	....

and when they were removed the mudstone formed cracks on the right side, parallel to the river bed, tending to permit the formation of open fissures and slides.

To maintain a stable equilibrium, the superintendent began to refill the river bottom with rolled material in the shortest possible time. The center fill was built to a height of 16 ft above the original river bed at the downstream end, or toe, of the dam. Here it was protected against erosion by a rock fill, covered with a network of broken dragline cable and reinforcing rods. The internal water pressure was relieved by drainage through the coarse rock fill. In the hope that it would afford added safety, this rock surface was lined with a layer of lean-mix concrete; but, although it was fairly strong in compression, it proved of little use as protection against erosion.

FIG. 3.—LOOSE ROCK FILL ALONG THE TOE OF AZÚCAR DAM IN TAMAULIPAS, JUNE 21, 1940

The building of the central part (that is, the river section) of the dam was suspended during 1940 and was not continued until August, 1941. The center section had reached a height that provided full safety against any further sloughing of the mudstone on the right bank. A construction view as of July, 1940, is shown in Fig. 3. Subsequently, the 1940 autumn floods, and those of the first seven months of 1941 (see Table 2), passed over the dam without the slightest erosion of the main body of the section. The fill in the river had been made on a small upgrade for the purpose of reducing velocities.

As shown in Fig. 4, however, there was some damage to the downstream toe of the rock dike and to the temporary concrete lining that had been poured the previous April 20; but the surviving steel mesh and concrete blanket were still sufficient to afford considerable protection against critical erosion. The lean-mix concrete blanket was a mix of 1.8 sacks (169 lb) of cement per cu yd of concrete in place. Because of its low resistance to erosion, a 4-in. layer of normal concrete was later poured over the weaker layer.

A three-day flood of variable magnitude (an undulating type) began on September 8, 1941, and reached its peak about September 10, when a discharge of 72,700 cu ft per sec was observed about 6 miles upstream by the IBC. Observing the elevation of flow near the crest, and estimating that the control tunnel could have diverted 10,200 cu ft per sec, about 62,500 cu ft per sec must have passed over the dam in this period. The result was that the protective lining (possibly because it was not high enough) was badly eroded. Nevertheless, it is worthy of note that, although the flanking failure of the blanket was in progress for three days, a relatively small volume of the rolled fill was washed downstream. The most serious erosion occurred on a strip of the river bank on the downstream left end of the rolled embankment where the natural uncompacted river terrace afforded the minimum resistance against erosion.

FIG. 4.—CONDITION OF AZÚCAR DAM IN TAMAULIPAS, OCTOBER 12, 1940, AFTER THE FLOODS OF 1939 AND 1940

Summary.—The original plans specified a protective spillway covering not to exceed the height of the by-pass channel leading to the spillway. The construction of a concrete overflow dam 50 ft high, closing the entrance to the spillway crest, was postponed until the embankment and the protective spillway had reached a sufficient height to pass even the record floods to be expected by means of the diversion tunnel and the spillway structure in the process of building without the smallest risk to the densely populated valley downstream from the dams.

At least six lessons were learned or corroborated during the construction of Azúcar Dam—

(1) The contractor must be acutely alert to guard against a flanking washout in the region of erodible material.

(2) When a concrete blanket is used for a protective lining the mix should be of normal quality or be covered with a layer of concrete to insure the required resistance to erosion.

(3) The crest should be raised in relatively small steps unless ample rock protection is available for larger steps, as in the case of Palmito Dam and Valsequillo Dam (described subsequently).

(4) Where the scarcity of rock dictates the use of a concrete cover an ample number of weep holes must be provided for the escape of infiltrating water to prevent uplift of the concrete blanket. This precaution is especially important where the fill is composed of fine or easily eroded material. No indication of uplift was detected at Azúcar Dam.

(5) As construction proceeds, the rolled surface should be sloped so that the downstream end of the embankment is maintained at a level not less than 3 ft higher than the upstream end so as to reduce the velocity of approach to the downstream crest. At Azúcar Dam the downstream level of each layer was always about 3 ft higher than the upstream end.

(6) Where rock or other resistant material is not available at the toe, a concrete apron must be provided to take the impact of the drop and to provide anchorage for the concrete blanket. This apron serves to prevent undercutting, the extent of which will depend on the cohesiveness of the material in the river channel.

Lazaro Cardenas (Palmito) Dam

Palmito Dam (see Table 1) is located on the Nazas River about 125 miles upstream from the City of Torreón, Coahuila, at the mouth of a canyon about

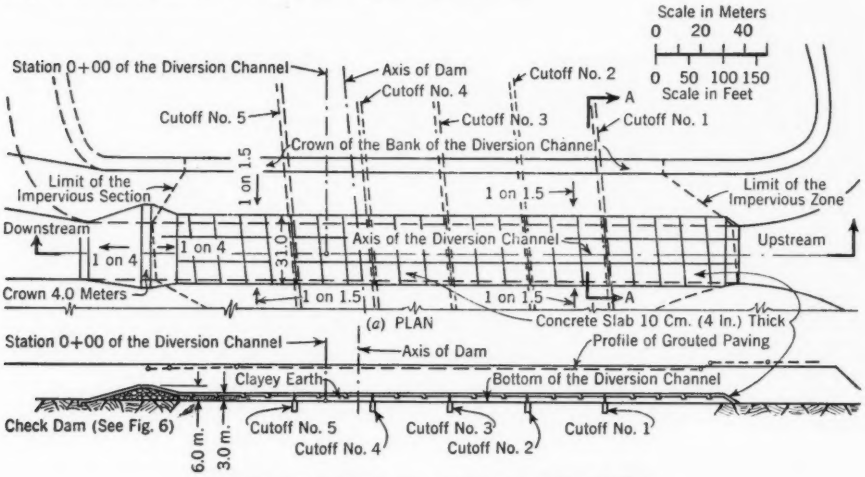
TABLE 3.—Record of Flood Discharges (Cubic Feet per Second) During the Construction of Palmito Dam in Durango

Month and day	1937	1938	1939	1940	1941	1942	1943
Feb. 16	....	....	....	....	....	10,650	....
June 23	....	....	....	....	....	....	7,600
June 30	....	9,750	....	8,790	....	....	....
July 2	....	....	....	....	....	....	10,900
July 27	....	52,500	....	....	9,980	....	....
August	....	....	....	....	16,200	....	....
Aug. 20	....	....	....	....	....	21,600	....
Aug. 21	....	....	21,800	....	....	....	....
Aug. 25	....	....	....	8,700	....	....	....
September	....	....	....	....	....	25,400	....
Sept. 12	....	....	....	....	51,600	....	....
Sept. 14	....	....	5,690	15,200	....	....	....
Sept. 19	49,300	57,000	....	....	....	....	....
Sept. 26	....	....	....	....	....	....	32,500
Oct. 9	....	....	....	....	....	6,150	....
Oct. 11	....	....	....	....	....	....	24,400
Oct. 12	....	....	....	....	6,140	....	....
Dec. 1	....	....	....	5,800	....	....	....
Dec. 12	....	....	....	....	19,200	....	....
Dec. 26	....	....	32,400	....	....	....	....

1.5 miles downstream from the confluence of its principal tributaries, the Oro and Ramos rivers in the State of Durango. The rocks exposed on both sides of this canyon, and in the river, consist of series of flows of rhyolites intercalated with rhyolitic tuffs of such highly variable structures and textures that

it was not possible to use the site for building a masonry dam of the gravity type. It was decided to use an earth-fill and rock-fill dam composed of a central impervious core of well compacted, gravelly earth and provided with pervious zones on both sides. On the upstream side the structure was made partly of a dumped rock fill composed of quarry-run rock and gravel; and, in the upper part, it comprised metamorphosed shales derived from the spillway excavation, compacted by rolling. On the downstream side the pervious zone was mostly composed of hard metamorphosed shale. The water side of the dam was further protected with a dumped rock fill placed in the form of an inverted filter with the coarsest material on top. The downstream side was protected against erosion by a hand-placed rock cover.

Because of the broken nature of the foundation rock it was blanket-grouted and provided with five cutoff walls, these provided with a grout curtain to a depth of 50 ft to secure a watertight foundation.



(b) SECTION ALONG THE AXIS OF THE DIVERSION CHANNEL

FIG. 5.—PLAN AND PROFILE OF DIVERSION CHANNEL, PALMITO DAM IN DURANGO

The agricultural development of the region being supplied from Palmito Dam (the so-called Laguna) was begun about 1880, and therefore a long rainfall and runoff record was available. During the construction of the dam the maximum discharges were as given in Table 3. The embankment slopes were as follows:

Description	Slope
Impervious central core, upstream side	1 on 2
Impervious central core, downstream side	1 on 1
Rock fill, downstream side	1 on 2.5
Rock fill, upstream side	1 on 3

The slope of the upstream side was broken at El. 5168 by a berm 33 ft wide. The diversion works comprised three tunnels, each 20 ft in diameter, and an open channel with a bottom width of 82 ft (see Fig. 5). The diversion provided

by the three tunnels and the open cut proved quite efficient. By far the greater part of the runoff was passed through the open cut, because the use of the tunnels was generally restricted during the years of construction—first by the excavation and the lining operations, and later by the building of the galleries which are used for the installation of the operating machinery.

All this work was much delayed by conditions existing during World War II. In the spring of 1941, when the end of the dam to the right of the diversion channel had been built to 150 ft above the river channel, it was decided to close the open cut. Hampered by the lack of equipment and by wartime conditions, it was decided to make this closing in successive stages, by a temporary spillway of a type similar to those used at Azúcar Dam, and, subsequently, at the Valsequillo Dam.

A plan was adopted to provide an overflow crest (Fig. 6) made of rock fill and covered with a concrete slab 20 cm (8 in.) thick, anchored to the rock at the foot of the downstream slope and to the rock on the left side and the grouted paving on the right. Also, it was decided to continue the concrete slab to cover the 10-ft thickness of fill in the bottom of the diversion channel, which corresponds to the height of the cutoff walls above the foundation of the impervious fill. The earth fill on the right of the diversion channel was protected with a layer of grouted paving as shown in Fig. 5.

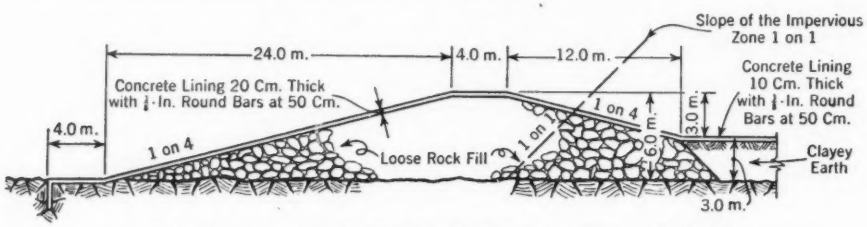


FIG. 6.—DETAIL OF OVERFLOW DAM (1 METER = 3.28 FT = 39.37 IN.)

On account of the broken nature of the rock in the bottom of the diversion channel at the lower end of the overflow crest it was decided to put the check dam at the lower end, about 40 ft upstream from the end of the impervious section. A discharge of about 10,500 cu ft per sec flowed through this channel on August 8, 1941, and continued at more or less the same rate for about three or four weeks (see Fig. 7). At this stage only one tunnel was available to supplement the diversion provided by the open channel. In this first stage in the construction of the spillway a maximum flood, on September 11, 1941, was 31,000 cu ft per sec. At the same time, 6,400 cu ft per sec passed through the tunnel, indicating a total of 37,400 cu ft per sec. The functioning of the temporary spillway was completely satisfactory.

The maximum flood for the entire year occurred on September 12. Of the total flow (51,600 cu ft per sec) about 42,000 cu ft per sec passed through the open cut and the remainder, through tunnel No. 3. After this flood, the spillway crest at the lower end of the diversion channel was raised 20 ft. The following flood did not reach the height of this crest, but passed through tunnel No. 3 with the help of the storage regulation provided by the reservoir; how-

ever, the flood of December 13, 1941, came close to reaching the height of the new crest.

Summary.—Although the results obtained with this open cut were entirely satisfactory, perhaps too great a risk was taken in making the second lift 20 ft high. A succeeding flood almost overtopped the overflow crest before it was ready. It is essential that the overflow crest be well protected against the danger of concentrated erosion, except where the deck is provided with a masonry or a concrete cover.

FIG. 7.—FLOW OF 10,600 CU FT PER SEC, THROUGH THE DROP AT THE LOWER END OF THE DIVERSION CHANNEL, PALMITO DAM IN DURANGO, AUGUST 8, 1941

After the flood of December 12–13, 1941, and those of January and February following, there was no further need for the temporary open waterway. It was then necessary to remove the protective lining of the spillway channel that passed through the impervious section of the dam and, finally, to complete the dam section as provided in the specifications. In this region the dry period extends from about the end of February until the following June. During this construction period it was estimated that any recorded flood of the preceeding 60 years could have been controlled by the three diversion tunnels, in combination with the impounding capacity of the reservoir.

AVILA CAMACHO (VALSEQUILLO) DAM

Valsequillo Dam is located on the Atoyac River, some 16 miles east of the City of Puebla, which is the capital city of the State of Puebla. It closes a narrow gorge about 50 ft wide with vertical and overhanging rock cliffs. The narrowness of the gorge suggested an ideal site for an arch dam, but this type was rejected after a thorough and careful exploration of the site, and a mixed type of rock-fill and earth-fill dam was selected.

Geologic conditions made this project a difficult one. The river bed had cut a narrow gorge about 100 ft deep into a limestone conglomerate, over which had been deposited beds of tuff and tepetate mixed with sandstone layers. The principal difficulty was the occurrence of many cracks and caverns, generally refilled with clays mixed with crushed rock. In many places these cracks had remained completely open, perhaps by reason of the erosion of such refill during the Quaternary period. The doubt which arose concerning the use of this site caused the National Commission of Irrigation to solicit the help of two consulting geologists (Charles P. Berkey, Hon. M. ASCE, and Kirk Bryan) and a consulting engineer John L. Savage, Hon. M. ASCE) to make two visits to this site at different stages of the explorations, and the results of their advice proved most valuable.

In addition to the data in Table 1, the slopes of this dam were as follows:

Description	Slope
Mixed earth core, both faces	1 on 1.25
Finished embankment, upstream face	1 on 2.25
Finished embankment, downstream face	1 on 2

The dam as designed had a spillway side channel with a fixed crest to serve a maximum flood height estimated at El. 6763.4 ft.

The impervious section of the dam was built of an altered conglomerate mixed with tuff. The latter was generally found in the borrow area close to the dam in a superficial deposit 10 ft or 20 ft thick underlain by the altered conglomerate. This material made an embankment more dense and impervious than the earth materials of fine texture, such as sandy loams and clay loams, which are usually found in the alluvial river terraces. Nevertheless, the building of the earth fill within the gorge was difficult because of the existence of the aforementioned innumerable fractures and cracks which it was necessary to clean thoroughly, refill, and grout so as to secure an effective closure. In the places where there were overhanging walls cutoff walls were built with the object of guarding against an imperfect closure, such as might occur as the result of a settlement of the compacted fill in succeeding years.

The treatment of the cracks in the canyon walls was so time consuming that the summer floods of 1943 became a menace. It was therefore resolved to apply the protective measures that had been used successfully at San Ildefonso and Azúcar, modified to suit the materials and local conditions. In this case it was expected that floods might overtop the earth fill to a height of 100 ft or more above the river channel. For this reason and because it was feared that trees and stumps might tear away a mesh of reinforcing bars, the engineers had some misgivings in using nothing more than the mesh of reinforcing bars such as were used at San Ildefonso. Therefore, it was resolved to use a concrete slab (see Figs. 8 and 9) reinforced with $\frac{5}{8}$-in.-round bars spaced 18 in. on centers in both directions. This deck was 16 in. thick in the lower section and was anchored to a cutoff wall at the bottom of the canyon, using $\frac{3}{4}$-in.-round bars. The thickness of the slab was maintained at 16 in. for a height of 33 ft measured from the anchor wall, and then it was reduced to 12 in. for the remainder of its height. The entire slab was anchored to the rock fill by $\frac{3}{4}$-in.-round bars, which extended into the loose rock about 6.5 ft and

were also anchored into the canyon walls by bars grouted into the rock, along both sides of the canyon. To prevent the slab from heaving as a result of possible uplift 6-in.-round weep holes were placed 6.5 ft on centers, along the entire surface.

The width of the gorge where the protective slab was placed varied from 40 ft to 50 ft. To provide the necessary access for the trucks which transported the materials and to cause a minimum interference with such transport, the slab was built in two abutting sections, each of which occupied one half of the gorge, and each half was raised alternately 5 ft vertically at a time (see Fig. 10). One half of the overflow crest at the lower end of the dam was thus always 5.0 ft higher than the other half.

FIG. 8.—PROTECTIVE DECK, VALSEQUILLO DAM IN PUEBLA, AFTER THE FLOOD OF MAY, 1943

FIG. 9.—UPLIFT DAMAGE, VALSEQUILLO DAM IN PUEBLA, AFTER THE FLOOD OF SEPTEMBER, 1943

Three floods overtopped the dam during the construction period in the summer of 1943, when the gorge was being filled. In May a flood overtopped the downstream crest 5.5 ft on the upper half and 10.5 ft on the lower half. The dam had been constructed to more than 52 ft above the stream bed. The width at each temporary crest level was 29.6 ft. The total of the discharge was estimated at 3,500 cu ft per sec.

A second flood, in August, raised the water surface to El. 6622.3, or 122 ft above the river bed. The higher half of the crest was at El. 6614.2 and the

lower half, at El. 6609.2. The width of the crest at this stage was 46 ft. The maximum discharge was estimated at 1,306 cu ft per sec.

In September, when the maximum elevation was 6,632 ft (132 ft above the river bed), a flood of 2,605 cu ft per sec occurred. The elevation of the higher half of the downstream crest was then 6,629.0 ft, that of the lower half was 6,624.0 ft, and the width of the gorge was 59 ft. Describing the effects of this flood, Guillermo Lugo, resident engineer, reported:

> "It is necessary to state as an important detail that at more or less half the height of the dam the concrete deck failed to cover the surface of the rockfill, lacking some 200 square ft. This was at a place in the gorge where the rock cliffs were badly fractured. A large portion of the water which passed freely through the downstream rockfill passed through these open spaces."

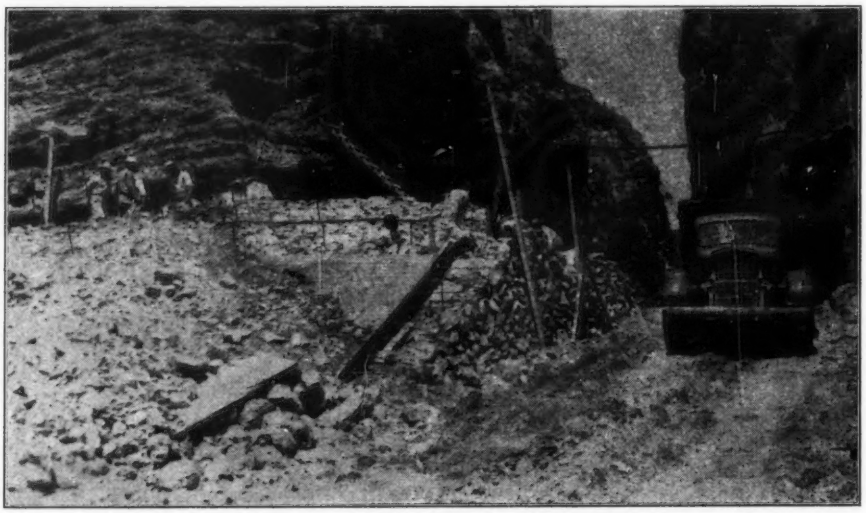


FIG. 10.—CONSTRUCTION ADAPTED TO TRANSPORTATION REQUIREMENTS, VALSEQUILLO DAM IN PUEBLA, MAY, 1943

At about half the height of the dam the concrete slab had been lifted clear of the surface of the rock fill, obviously because of insufficient weep hole capacity (see Fig. 9). The amount of this lift was about 1 ft. The water passed freely through the rock fill and escaped, as indicated by Mr. Lugo, in the openings left in the concrete slab not only at a place approximately half the height of the dam, but also near the bottom of the concrete slab.

In spite of these imperfections (caused by the uplift of the concrete slab and the escape of water through the openings near the rock cliffs) the dam showed no signs of settlement or deterioration, which leads to the belief that a simple mesh of reinforcing bars might have been sufficient to protect the dam, in the same manner as it did at San Ildefonso. The gradation of the rockfill on the downstream section of the dam proved effective protection against any erosion of the impervious core.

Summary.—The region downstream from this dam is sparsely populated and relatively greater risks could be taken without serious danger to human life or property. Furthermore, the rock walls on both sides of the canyon, the relatively small catchment area, and the ample and well graded rock fill on the downstream slope of the dam, protected by a securely anchored concrete slab, made a failure during construction a virtual impossibility.

Similar Protective Works at Other Dams

The Ministry of Hydraulic Resources has found it necessary to adapt similar types of protective measures in the construction of other dams in Mexico. In one of these (the Solis Dam in the State of Guanajuato) a mesh of reinforcing bars was placed similar to that used at San Ildefonso Dam. No flood occurred during construction, and therefore its efficacy was never tested. In another (Cuarenta Dam in the State of Jalisco), the largest flood reached the (then) level of the overflow crest at the downstream face, with insufficient volume to spill over. No doubt the reinforcing bar mesh would have held the rock in place.

A third case of flood protection which was well handled by the contractor was the Sanaloma Dam on the Tamazula River some 16 miles upstream from the City of Culiacan in the State of Sinaloa. In this case a channel was left open along the right end of the dam. The mountain at that end was composed of a weathered granite and the embankment on the left of the open channel was a well compacted rolled fill made of an altered conglomerate.

In a compacted condition, this material resisted erosion unusually well, as had been previously determined by observing the effects of floods in the preceeding season.

Conclusion

As was to be expected, each dam described in this paper presented a distinct problem. The irregularity of flood incidence along the Gulf Coast is in marked contrast to the more regular occurrence of a rainy season in the interior of Mexico. Along the west coast there are two flood seasons each year—the summer rains of August and September and the winter rains of December and January. In the interior, the six months from November to April are usually dry, whereas the dry season along the Gulf Coast cannot be so readily marked.

The single element that characterized the projects described in the paper was the complete cooperation of the principal personal elements interested, and of the central office. There was no desire to display originality of concept involving undue risk, or to curb any individual effort exerted to the desired ends. The only partial failure, at Azúcar Dam, was promptly and most satisfactorily met by the immediate and most effective cooperation of the field forces, in a period of sweltering and enervating heat, at a time just preceding the national holidays of September 15, and 16, when it is customary for all employees to enjoy a well earned vacation and rest.

There is no doubt that the principles employed can be adapted successfully in many other cases, with notable success and with significant savings in construction cost. It must be clearly understood, however, that these are con-

struction expedients and are not to be accepted as standards for a general application to other cases. Even during construction, it is recommended that no risk be taken that would be even approximately comparable to the breaching of a completed structure. Particularly important is the selection of engineering personnel with innate initiative, experience, and common sense, who are able to interpret their own past experiences and apply them conservatively to new and unexpected field problems.

Acknowledgment

The dams mentioned in this paper form a part of the irrigation system constructed by the Ministry of Hydraulic Resources, formerly the National Irrigation Commission of Mexico. The National Irrigation Commission was headed by Marte R. Gómez, president, and Adolfo Orive Alba, executive commissioner and minister in charge, with Eugenio Riquelme as assistant minister.

AMERICAN SOCIETY OF CIVIL ENGINEERS

OFFICERS FOR 1950

PRESIDENT

ERNEST E. HOWARD

VICE-PRESIDENTS

Term expires January, 1951:

HENRY J. SHERMAN
ROBERT B. BROOKS

Term expires January, 1952:

FRED C. SCOBEY
ALBERT HAERTLEIN

DIRECTORS

Term expires January, 1951:

WILLIAM M. GRIFFIN
KIRBY SMITH
FRANCIS S. FRIEL
JULIAN HINDS
WEBSTER L. BENHAM
C. GLENN CAPPEL

Term expires January, 1952:

WALDO G. BOWMAN
MORRIS GOODKIND
HAROLD L. BLAKESLEE
PAUL L. HOLLAND
EDMUND FRIEDMAN
S. T. HARDING

Term expires January, 1953:

OTTO HOLDEN
FRANK L. WEAVER
GORDON H. BUTLER
LOUIS R. HOWSON
G. BROOKS EARNEST
WALTER J. RYAN
GEORGE W. LAMB

PAST-PRESIDENTS

Members of the Board

R. E. DOUGHERTY
FRANKLIN THOMAS

TREASURER
CHARLES E. TROUT

EXECUTIVE SECRETARY
WILLIAM N. CAREY

ASSISTANT TREASURER
GEORGE W. BURPEE

ASSISTANT SECRETARY
E. L. CHANDLER

PROCEEDINGS OF THE SOCIETY

SYDNEY WILMOT
Manager of Technical Publications

HAROLD T. LARSEN
Editor of Technical Publications

COMMITTEE ON PUBLICATIONS

WALDO G. BOWMAN

FRANCIS S. FRIEL
S. T. HARDING
KIRBY SMITH
OTTO HOLDEN
LOUIS R. HOWSON